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Protection Against Radiations From Radium, Cobalt-60, and Cesium-137

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Curie (c). A unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

Daily. During each 24-hr period.

Danger range. Distance from a source of radioactive material at which the gamma radiation is 6.25 mr/hr (0.00625 r/hr).

$$\text{D. R. (cm)} = \sqrt{\frac{I\gamma \times \text{mc}}{0.00625}}$$

See definition of $I\gamma$. (6.25 mr/hr corresponds to 300 mr for a 48-hr week.)

Danger range, specific. Danger range in centimeters for an unshielded point source of 1 mc of a given radioactive substance.

Decay, radioactive. Spontaneous change of a nucleus with emission of a particle or a photon; rate of decay is usually expressed in terms of *half life.*

Dose. The quantity of radiation delivered to a specified mass or volume. Dose units are: the roentgen (r) for gamma rays, the rad for gamma and beta rays. In radiology the dose may be specified in air, on the skin, or at some depth beneath its surface; no statement of dose is complete without specification of location at which the dose is considered. Unless otherwise specified, in this Handbook dose refers to the dose in air, measured without backscatter.

Dose rate. Dose per unit time.

Dose-rate meter. Instrument for measuring dose rate.

Dosimeter. Instrument for measuring total dose.

Exposure. See *dose* (measured in air, without backscatter).

Film badge. An appropriately packaged photographic film for detecting radiation received by persons. It is usually dental-film size, and worn or carried on the person.

Gamma rays. Electromagnetic radiation of short wavelength and correspondingly high frequency, emitted by nuclei in the course of radioactive decay.

Geometry. Relative arrangement of source and measuring system.

Half life, radioactive. Time for the activity of any particular radioisotope to be reduced to half its initial value.

Half-value layer (HVL). Thickness of an absorber required to reduce a beam of radiation to one-half its incident dose rate.

Hazard, radiation. See *radiation hazard.*

$I\gamma$. Roentgens per millicurie-hour at 1 cm from an un-

TABLE 1. *Radiations emitted by certain isotopes* [a]

Isotope	Radiation		Range	
	Type	Energy	Air	Aluminum
Radium series:		*Mev*	*cm*	*mm*
Radium-226	Alpha	4.79, 4.61	3.1	--------
	Gamma	0.18	----	--------
Radon-222	Alpha	5.49	3.9	--------
Polonium-218 (radium A)	Alpha	6.0	4.5	--------
Lead-214 (radium B)	Beta	0.65	----	0.9
	Gamma	0.24 to 0.35	----	--------
Bismuth-214 (radium C)	Beta	1.65, 3.15	----	5.9
	Gamma	0.42 to 2.4	----	--------
	Alpha	5.5	3.9	--------
Polonium-214 (radium C′)	Alpha	7.68 to 10.5	6.6	--------
Thallium-210 (radium C″)	Beta	1.8	----	3.1
	Gamma	approx. 5	----	--------
Lead-210 (radium D)	Beta	0.029	----	0.006
	Gamma	0.007 to 0.047	----	--------
Bismuth-210 (radium E)	Beta	1.17	----	1.9
Polonium-210 (radium F)	Alpha	5.3	3.6	--------
Cobalt-60	Beta	0.31	----	0.31
	Gamma	1.17, 1.33	----	--------
Cesium-137	Beta	0.51, 1.2	----	2.0
	Gamma	0.661	----	--------

[a] Nuclear Data, National Bureau of Standards Circular 499.

TABLE 2. *Occupancy factors.*

For use as a guide in planning shielding where complete occupancy data are not available.

Full occupancy (T=1)
Control space, residences, wards, office workrooms, darkrooms, corridors and waiting space large enough to hold desks, rests rooms used by the radiologic staff and others routinely exposed to radiation, play areas.
Partial occupancy (T=1/4)
Corridors in X-ray departments too narrow for future desk space, rest rooms not used by radiologic personnel, parking lots, utility rooms.
Occasional occupancy (T=1/16)
Stairways, automatic elevators, streets, closets too small for future workrooms, toilets not used by radiologic personnel.

TABLE 3. *Possible teletherapy sources.*

Although the present scope of this Handbook is limited to radium, cobalt-60, and cesium-137; other isotopes are included in this table, since they are currently under investigation for teletherapy. Most of these figures are based on incomplete but the best available data. The basic problems of protection are common to all.

Isotope	Half-life	Gamma energy	Practical clinical form	Production	Highest practical-volume specific activity	Specific gamma exposure rate
		Mev			[c] *Curies/cm*^{3}	*r/curie-hr at 1 m* [d]
Radium-226	1,620y	0.2 to 2.2	Sulfate	Natural	4	[e] 0.84
Cesium-137	33y	0.661	Sulfate	Fission	100	0.39
Europium-152-154	12.4y	[a] 1.0	Oxide	Nuclear reactor	5,000	0.7
Cobalt-60	5.3y	1.17, 1.33	Metal	do	1,000	1.35
Cesium-134	2.3y	0.5 to 1.3	Sulfate	do	1,000	1.2
Cerium-144	275d	[b] 0.6, 2.6	Oxide	Fission	2,000	0.2
Silver-110	270d	0.6 to 1.5	Metal	Nuclear reactor	250	1.4
Thulium-170	127d	0.08	Oxide	do	500	0.01
Tantalum-182	117d	0.04 to 1.2	Metal	do	1,500	0.6
Scandium-46	85d	0.9, 1.1	Oxide	do	500	1.1
Terbium-160	74d	0.1 to 1.1	Chloride	do	50	0.3
Iridium-192	70d	0.1 to 0.6	Metal	do	1,000	0.3

[a] Following filtration with 3.0 mm of lead, 83 percent of total radiation appears to be from four high-energy photons averaging 1.08 Mev.
[b] Gamma activity from 17-min praseodymium daughter; energy levels are doubtful.
[c] One year irradiation in 5×10^{13}n/cm^2/sec, 1 year after removal from reactor, ideal geometry, for neutron reactions.
[d] Assuming that gamma absorption in the source is negligible.
[e] This assumes the source is sealed within a 0.50-mm-thick platinum capsule.

TABLE 4. *Primary-protective-barrier requirements for teletherapy*

Work load equal to 80,000 r/week at 1 m

Source-to-occupied-space distance		Radium			Cobalt-60			Cesium-137		
		Concrete	Steel	Lead	Concrete	Steel	Lead	Concrete	Steel	Lead
m	*ft*	*in.*	*in.*	*cm*	*in.*	*in.*	*cm*	*in.*	*in.*	*cm*
3	--	42.5	13.4	23.1	38	12.6	19.2	30	10.9	9.6
	10	42	13.4	23.1	38	12.6	19.2	30	10.9	9.5
4	--	40	12.6	21.6	36	11.8	18.2	29	9.3	9.0
	15	39	12.2	20.9	35	11.6	17.6	28	9.1	8.8
5	--	38	12.0	20.4	34.5	11.4	17.4	27.5	8.9	8.6
	20	36.5	11.4	19.3	33	10.8	16.6	26	8.5	8.2
7	--	35.5	11.0	18.6	32	10.4	16.1	25.5	8.3	7.9
	25	34.5	10.8	18.1	31.5	10.2	15.7	25	8.2	7.8
8	--	34.5	10.8	17.9	31	10.2	15.6	25	7.9	7.7
	30	33.5	10.4	17.2	30.5	9.8	15.1	23	7.8	7.5
10	--	32.5	10.2	16.8	29.5	9.6	14.8	22.5	7.6	7.3
Approximate HVL thickness		2.6	0.9	1.3	2.5	0.9	1.2	1.9	0.65	0.6

TABLE 5. *Protective barrier for scattered radiation in teletherapy* [a]

Work load equal to 80,000 r/week at 1 m

Scatterer-to-occupied-space distance		Radium and cobalt-60		Cesium-137	
		Concrete	Lead	Concrete	Lead
m	*ft*	*in.*	*mm*	*in.*	*mm*
3	------	11.9	18.3	9.8	8.8
	10	10.8	18.1	9.7	8.7
4	------	9.6	15.0	8.6	7.3
	15	9.0	13.6	8.0	6.6
5	------	8.6	12.9	7.6	6.3
	20	7.8	11.0	6.9	5.1
7	------	7.1	10.5	6.3	4.6
	25	6.8	8.6	6.0	4.2
8	------	6.5	8.3	5.7	4.0
	30	5.9	7.3	5.1	3.3
10	------	5.5	6.9	4.8	2.9
Approximate HVL thickness		1.6	[b] 3.3	1.4	[b] 1.9

[a] Shielding required to reduce the scattered radiation to 0.3 r/week for a work load of 80,000 r/week at 1 m and occupancy factor of 1. See table 6 for the number of half-value layers to be subtracted for other work loads. The barrier for leakage radiation will depend upon the leakage permitted by the source housing.

[b] These values are only for estimating purposes, since they vary considerably over the range of attenuations of interest.

TABLE 6. *Corrections to tables 4 and 5 for other work loads*

Work load (r/week at 1 m)	Number of HVL to be added or subtracted	Work load (r/week at 1 m)	Number of HVL to be added or subtracted
2, 500	−5. 0	40, 000	−1. 0
5, 000	−4. 0	80, 000	0
10, 000	−3. 0	160, 000	+1. 0
20, 000	−2. 0		

TABLE 7. *Relation between distance and millicurie-hours for an exposure of 0.3 r from an unshielded source*

Millicurie-hours	Distance to source		
	Radium	Cobalt-60	Cesium-137
	ft	*ft*	*ft*
10	0. 5	0. 7	0. 4
30	1. 0	1. 2	0. 6
100	1. 8	2. 2	1. 2
300	3. 0	3. 8	2. 1
1, 000	5. 5	7. 0	3. 7
3, 000	9. 5	12	6. 5
10, 000	18	22	12

TABLE 8. *Protection requirements for radium in centimeters of lead*

Milligrams of radium	Thicknesses of lead required at a distance of—		
	30 cm	1 m	2 m
48 hr/week			
	cm	*cm*	*cm*
25	6. 6	1. 9	0
50	8. 1	3. 3	0. 7
75	9. 0	4. 0	1. 3
100	9. 6	4. 6	1. 9
200	11. 1	6. 0	3. 3
12 hr/week			
25	3. 8	0	0
50	5. 2	0. 7	0
75	6. 1	1. 3	0
100	6. 6	1. 9	0
200	8. 1	3. 3	0. 7
6 hr/week			
25	2. 5	0	0
50	3. 8	0	0
75	4. 6	0. 3	0
100	5. 2	0. 7	0
200	6. 6	1. 9	0

Table 9. *Protection requirements for cobalt-60 in centimeters of lead*

Cobalt (rhm)	Thicknesses of lead required at a distance of—		
	30 cm	1 m	2 m
48 hr/week			
	cm	*cm*	*cm*
0.1	9.4	5.5	3.0
0.3	11.3	7.5	5.0
1.0	13.4	9.5	7.1
3.0	15.4	11.4	9.0
10.0	17.7	13.6	11.1
12 hr/week			
0.1	7.0	3.0	0.6
0.3	8.9	5.0	2.6
1.0	11.0	7.2	4.7
3.0	13.0	9.1	6.6
10.0	15.1	11.1	8.6
6 hr/week			
0.1	5.8	1.8	0
0.3	7.7	3.9	1.3
1.0	9.7	5.9	3.5
3.0	11.7	7.8	5.4
10.0	13.9	10.0	7.5

Table 10. *Protection requirements for cesium-137 in centimeters of lead*

Cesium (rhm)	Thicknesses of lead required at a distance of—		
	30 cm	1 m	2 m
48 hr/week			
	cm	*cm*	*cm*
0.01	2.7	0.7	0
0.03	3.7	1.65	0.35
0.1	4.85	2.8	1.5
0.3	5.9	3.8	2.5
1.0	7.0	4.95	3.6
12 hr/week			
0.01	1.4	0	0
0.03	2.4	0.35	0
0.1	3.55	1.5	0.15
0.3	4.6	2.55	1.2
1.0	5.75	3.65	2.35
6 hr/week			
0.01	0.8	0	0
0.03	1.75	0	0
0.1	2.95	0.9	0
0.3	3.95	1.9	0.55
1.0	5.05	3.0	1.7

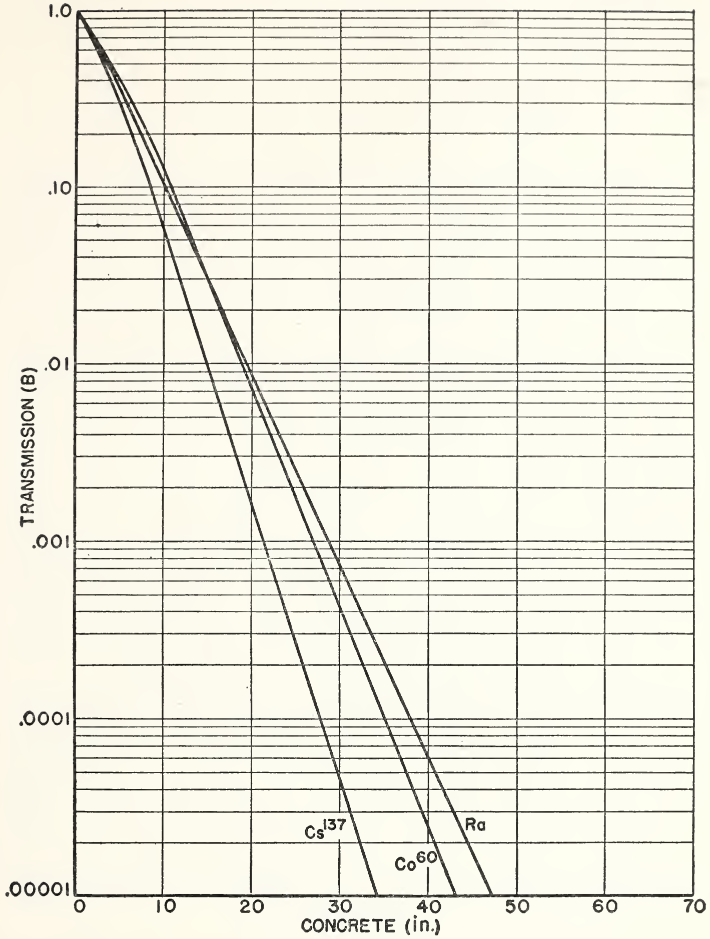

FIGURE 5. *Transmission through concrete (specific gravity 147 lb/ft³) of gamma rays from radium, cobalt-60, and cesium-137.*

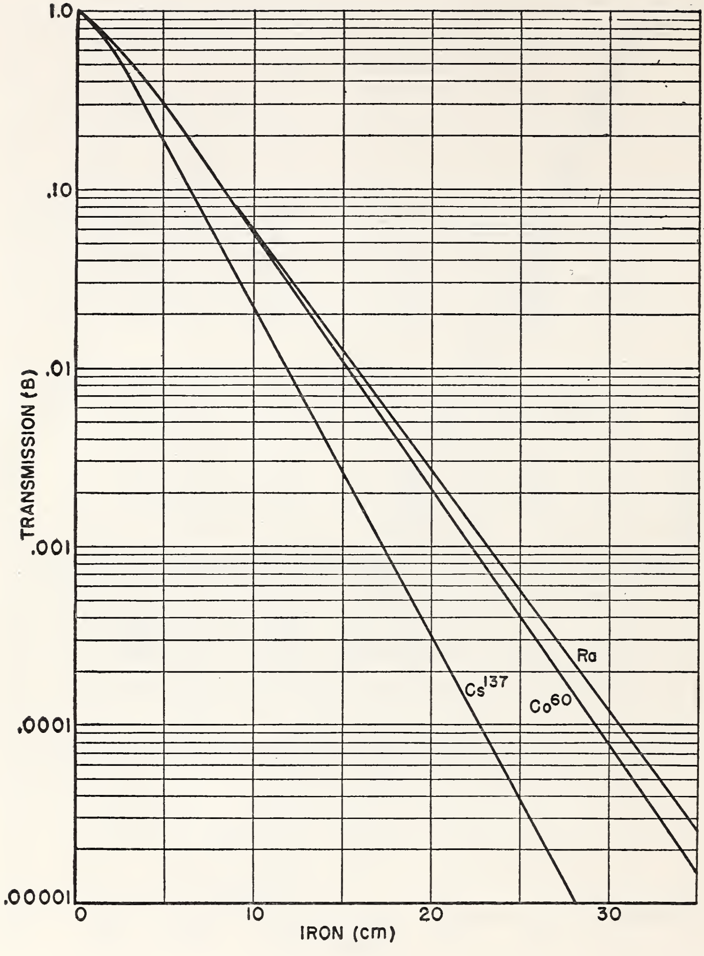

FIGURE 6. *Transmission through iron of gamma rays from radium, cobalt-60, and cesium-137.*

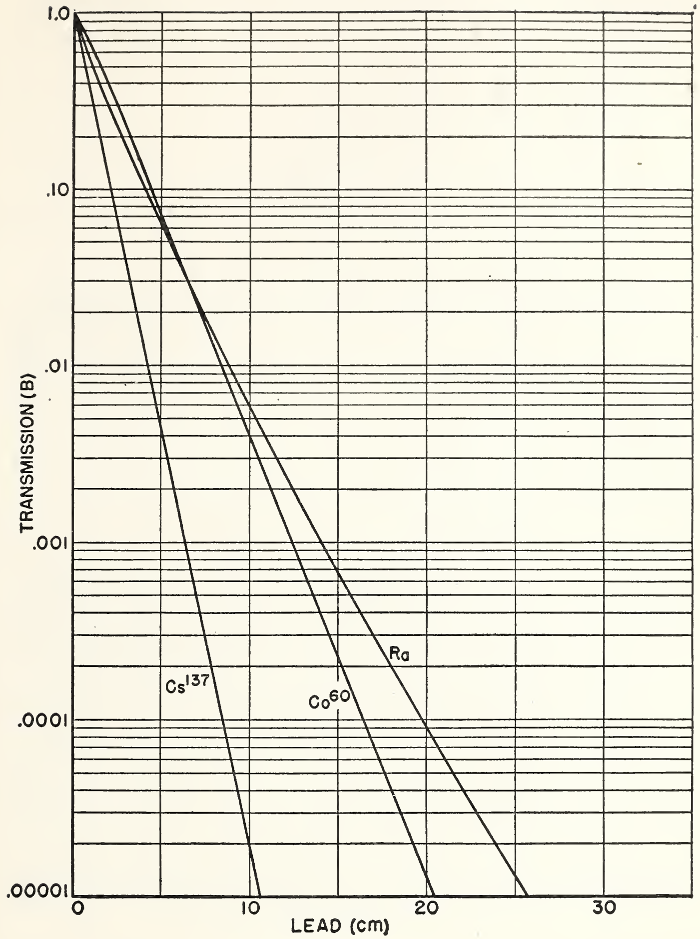

FIGURE 7. *Transmission through lead of gamma rays from radium, cobalt-60, and cesium-137.*

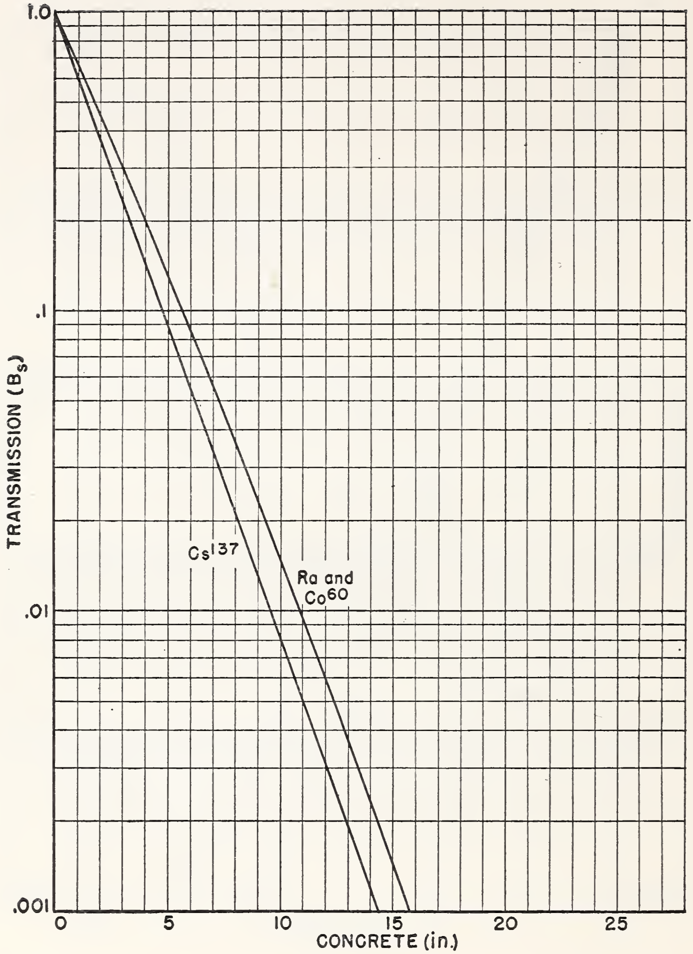

FIGURE 8. *Transmission through concrete (specific gravity 147 lb/ft³) of 90-degree-scattered gamma rays from radium, cobalt-60, and cesium-137.*

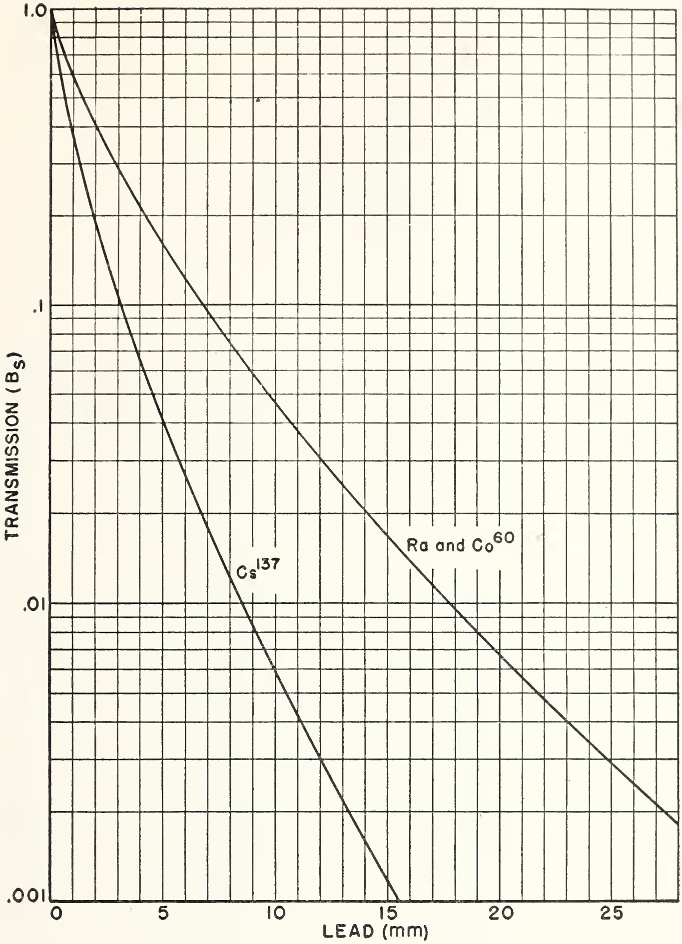

FIGURE 9. *Transmission through lead of 90-degree-scattered gamma rays from radium, cobalt-60, and cesium-137.*